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Determination of Thiocarbamates in Industrial and Municipal Wastewater Butylate, Cycloate, EPTC, Molinate, Pebulate, and Vernolate

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DETERMINATION OF THIOCARBAMATES IN INDUSTRIAL AND MUNICIPAL WASTEWATER - BUTYLATE, CYCLOATE, EPTC, MOLINATE, PEBULATE, AND VERNOLATE

by

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Contract No. 68-03-2956

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The final method was applied to Columbus Publicly Owned Treatment Works (POTW) secondary effluent in order to determine the precision and accuracy of the method. The wastewater was spiked with the six compounds at levels of 5 µg/L and 50 µg/L; recoveries were in the 80 to 100 percent range at both concentration levels. Method detection limits (MDLs) for the six compounds in distilled water were in the 0.6 to 1.6 µg/L range. In wastewaters, MDLs may be higher due to interfering compounds.

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FOREWORD

Environmental measurements are required to determine the quality of ambient waters and the character of waste effluents. The Environmental Monitoring and Support Laboratory - Cincinnati, conducts research to:

- Develop and evaluate methods to measure the presence and concentration of physical, chemical, and radiological pollutants in water, wastewater, bottom sediments, and solid wastes.

- Investigate methods for the concentration, recovery, and identification of viruses, bacteria, and other microbiological organisms in water; and, to determine the responses of aquatic organisms to water quality.

- Develop and operate a computerized system for instrument automation leading to improved data collection, analysis, and quality control.

- Develop and operate an Agency-wide quality assurance program to assure standardization and quality control of systems for monitoring water and wastewater.

This report is one of a series that investigates the analytical behavior of selected pesticides and suggests a suitable test procedure for their measurement in wastewater. The method was modeled after existing EPA methods being specific yet as simplified as possible.

Robert L. Booth, Director
Environmental Monitoring and Support
Laboratory - Cincinnati

ABSTRACT

A method was developed for the determination of six thiocarbamate compounds (butylate, cycloate, EPTC, molinate, pebulate, and vernolate) in wastewaters. The method development program consisted of a literature review; determination of extraction efficiency for each compound from water into methylene chloride; development of a deactivated silica gel cleanup procedure; and determination of suitable gas chromatographic analysis conditions.

The final method as applied to Columbus Publicly Owned Treatment Works (POTW) secondary effluent in order to determine the precision and accuracy of the method. The wastewater was spiked with the six compounds at levels of 5 µg/L and 50 µg/L; recoveries were in the 80 to 100 percent range at both concentration levels. Method detection limits (MDLs) for the six compounds in distilled water were in the 0.6 to 1.6 µg/L range. In wastewaters MDLs may be higher due to interfering compounds.

This report was submitted in partial fulfillment of Contract No. 68-03-2956 by Battelle Columbus Laboratories under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from August 1, 1981 to April 30, 1982.

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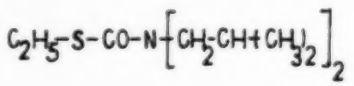
SECTION 1

INTRODUCTION

The group of compounds designated as the "thiocarbamates" is made up of six thiocarbamate compounds, namely butylate, cycloate, EPTC, molinate, pebulate, and vernolate. Although these compounds are not necessarily expected to be found together in wastewaters, they were similar enough in structure to be combined for method development and validation purposes.

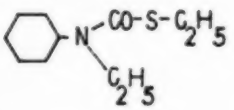
Butylate (I) is used for control of broad-leaved and grass weeds in maize.



I

Its CAS registry number is 2008-41-5 and its IUPAC name is S-ethyl-N,N-diisobutylthiocarbamate. Some of its common synonyms are "R-1910", "Sutan", and "Butilate". The acute oral LD50 in rats of butylate is 4700 mg/kg and it is stable in water. A literature search yielded descriptions of analytical methods including thin-layer chromatography, (TLC) (1) and packed column GC using electroconductivity (2) and flame photometric (3,4) detectors. Columns used for GC analyses included 3% OV-101, 1% OV-17, and 1% Carbowax 20M (2), and 10% OV-17 (3,4).

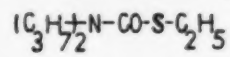
Cycloate (II) is toxic to germinating seeds and is used for the control of annual broad-leaved weeds and grasses.



II

Its CAS registry number is 1134-23-2 and its IUPAC name is S-ethyl N-cyclohexyl-N-ethyl thiocarbamate. Common synonyms for cycloate include "Ro-neet", "Ronit", "Eurex", and "R-2063". The acute oral LD50 of cycloate in rats in 3200 mg/kg and it is stable in water under normal conditions of pH and temperature. A literature search yielded descriptions of analytical techniques such as TLC (1) and packed GC using a flame photometric detector on a 10% OV-17 column (4).

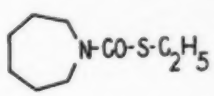
EPTC (III) kills germinating seeds and inhibits bud development from underground portions of some perennial weeds.



III

Its CAS registry number is 759-94-4 and its IUPAC name is S-ethyl dipropylthiocarbamate. Common synonyms for EPTC include "R-1608", "Eptan", "FDA 1541", "Eptam 6E", and "Torbin". The acute oral LD50 in rats of EPTC is 1700 mg/kg and it is stable in water under normal conditions of temperature and pH. A literature search yielded a description of an extraction method from soils using acetone and subsequent cleanup using Florisil (2). Analysis methods were described using TLC (6) and GC with a Hall detector (2) or a flame photometric detector (4). Columns used for GC analyses included 3% OV-101, 1% OV-17, and 1% Carbowax 20M (2), and 10% OV-17 (4). Electron impact mass spectral information (2,5) and stability data (6) were also reported.

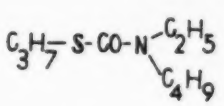
Molinate (IV) is toxic to germinating broad-leaved and grassy weeds.



IV

Its CAS registry number is 2212-67-1 and its IUPAC name is S-ethyl N,N-hexamethylenethiocarbamate. Some common synonyms for molinate are "R-4572", "Hydram", "Yalan", "Ordram", "Jalan", "Yulan", "Felan", and "Yalam". The acute oral LD50 in rats for molinate is 500-720 mg/kg and it is stable in water under normal conditions of temperature and pH. A literature search yielded suggested extraction solvents of hexane or ethyl acetate (7) and descriptions of analysis methods such as TLC (6) and GC using a flame photometric detector and 5% OV-101, 5% OV-17, 5% OV-210, and 5% OV-255 (8) and 10% OV-17 (4) columns. Hydrolysis data were also reported (7).

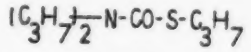
Pebulate (V) is a preemergent herbicide for control of annual grasses, sedges, and broad-leaved weeds.



V

Its CAS registry number is 1114-71-2 and its IUPAC name is S-propyl butylethylthiocarbamate. Common synonyms for pebulate include "R-2061", "PEBC", and "Tillam". The acute oral LD50 in rats for pebulate is 920-1100 mg/kg and it is stable in water under normal conditions of pH and temperature. A literature search yielded desriptions of analysis techniques including TLC (6) and GC using Hall (2) and flame photometric (8,4) detectors. Columns used for GC analyses include 3% OV-101, 1% OV-17, and 1% Carbowax 20M (2), 5% OV-101, 5% OV-17, 5% OV-210, and 5% OV-255 (8), and 10% OV-17 (4). Stability of pebulate in acidic and basic media was also reported (1).

Vernolate (VI) is toxic to germinating broad-leaved and grassy weeds.



VI

Its CAS registry number is 1929-77-7 and its IUPAC name is S-propyl-N,N-dipropylthiocarbamate. Common synonyms for vernolate include "PPTC", "Vernam", "Vanalate", and "R-1607". The acute oral LD50 in rats for vernolate in 1800 mg/kg and it is stable in water under normal conditions of pH and temperature. A literature search yielded descriptions of an extraction procedure for sediments using benzene (2) and GC analysis methods using Hall (2) and flame photometric (4) detectors. Columns used for GC-MS analysis included 3% OV-101, 1% OV-17, and 1% Carbowax 20M (2), and 10% OV-17 (4). Chemical ionization mass spectral information was reported (2) as well as acidic and basic hydrolysis data (6).

The resultant analytical method which was produced is included in Appendix A of this report.

SECTION 2

CONCLUSIONS

EXTRACTION AND CONCENTRATION

The six thiocarbamates can be extracted with methylene chloride from water with greater than 85 percent recovery using continuous extraction techniques. Use of Kuderna-Danish (K-D) equipment to perform extract concentrations did not lead to significant recovery loseses.

CLEANUP

The thiocarbamates elute from six percent deactivated silica gel in 50 percent ethyl ether in petroleum ether or less polar solvents. Recoveries greater than 90 percent are obtained. This use of deactivated silica gel was an effective cleanup procedure for extracts from a Columbus POTW secondary effluent.

CHROMATOGRAPHY

Two packed GC column, 3% SP-2250 and 3% SP-1000, were found to be acceptable for the GC-AFD analysis of these compounds. The 3% SP-2250 column gave better peak shape for the thiocarbamates and was designated as the primary column. The 3% SP-1000 column was used as the secondary column.

VALIDATION STUDIES

Recoveries of the six thiocarbamates from water at concentrations ranging from 10 to 1000 µg/L were generally greater than 85 percent resulting in linear analytical curves. The MDLs ranged from 0.6 to 1.6 µg/L for all of the compounds. Recoveries of the thiocarbamates from Columbus POTW secondary effluent at the 5 and 50 µg/L level were greater than 85 percent except for butylate at the 5 µg/L level (80 percent).

SECTION 3

EXPERIMENTAL

Studies were performed to determine if techniques such as separatory funnel extraction, continuous extraction, silica gel adsorption chromatography cleanup, K-D apparatus concentration, and packed column GC-AFD analysis would be applicable to the determination of the six thiocarbamates in wastewaters. Since recovery data and literature references indicated that these compounds are relatively stable in water, stability studies were not performed.

EXTRACTION AND CONCENTRATION

One liter of spiked distilled water was placed in a two-liter separatory funnel the pH was adjusted to 7 by addition of 6 N sodium hydroxide or 6 N sulfuric acid, and 100 g of NaCl was added. The sample was extracted three times with 60 mL each of methylene chloride. The combined extracts were dried by passing them through 10 cm of anhydrous granular sodium sulfate and then concentrated to one mL. These extractions were done in duplicate at concentration levels of 100 and 500 µg/L.

Continuous extraction of the compounds from water into methylene chloride was also studied. The pH of one liter of spiked distilled water was adjusted to 7 by addition of 6 N sodium hydroxide or 6 N sulfuric acid and extracted overnight with methylene chloride in a continuous extractor. The methylene chloride extract was dried and concentrated to one mL as described above.

CLEANUP

Activated silica gel, 20 grams, was stirred with 100 mL of acetone and 1.2 mL of reagent water for 30 minutes. The slurry was transferred to a chromatographic column, and the solvent was allowed to elute and discarded. The column was then sequentially washed with 20 mL of methylene chloride and 30 mL of petroleum ether. Petroleum ether, 50 mL, was suspended over the silica gel. The six compounds dissolved in one mL of methylene chloride were added to the above mentioned petroleum ether. This solvent plus an additional 50 mL of petroleum ether were eluted from the column and collected (F1). Nine additional 25 mL solvent elutions were collected; six percent ethyl ether in petroleum ether (F2); 15 percent ethyl ether in petroleum ether (F3); 50 percent ethyl ether in petroleum ether (F4); ethyl ether (F5); six percent acetone in ethyl ether (F6); 15 percent acetone in ethyl ether (F7); 50 percent acetone in ethyl

ether (F8); acetone (F9); and six percent methanol in acetone (F10). Each fraction was concentrated to one mL. This experiment was done in duplicate with 10 µg of each of the thiocarbamates and once with 100 µg of each of the thiocarbamates.

CHROMATOGRAPHY

Two columns, 3% SP-2500 amd 3% SP-1000, were evaluated for the determination of the thiocarbamates.

VALIDATION STUDIES

The MDLs for the six compounds were determined by analyzing seven replicate distilled water samples spiked at the 5 µg/L concentration level. The amounts recovered were determined by external standard calibration and the MDLs calculated from these data.

Distilled water was also spiked in duplicate at the 10, 50, 100, 500, and 1000 µg/L concentration levels; recoveries of the six compounds were determined as described earlier. An analytical curve was generated for each compound by plotting the amount spiked into the samples versus the amount recovered from the samples.

Columbus POTW secondary effluent was used for method validation studies. Seven aliquots of each wastewater were analyzed to determine levels of interferences. The Columbus POTW secondary effluent was spiked with the six thiocarbamates at the 5 and 50 µg/L levels, processed, and analyzed. Seven replicate extractions were performed at each concentration level.

The silica gel cleanup procedure described in the attached method was used for all of the validation studies. One fraction consisting of 100 mL of 50% ethyl ether in petroleum ether was collected, concentrated, and used for subsequent GC-AFD analyses.

SECTION 4

RESULTS AND DISCUSSION

EXTRACTION AND CONCENTRATION

The six thiocarbamates were extracted from distilled water into methylene chloride with generally greater than 85 percent recovery if continuous extraction was used. Use of separatory funnels for extractions resulted in slightly lower recoveries particularly at the lower concentration level of 100 µg/L. Recovery data from duplicate extractions at the 100 and 500 µg/L concentration levels using separatory funnels and 10 and 100 µg/L levels using continuous extractors are given in Table 1.

TABLE 1. EXTRACTION OF THIOCARBAMATES FROM WATER

Compound	Recovery Using Specified Technique, %(a)			
	Separatory Funnel		Continuous Extraction	
	100 µg/L	500 µg/L	10 µg/L	100 µg/L
Butylate	71(0)	98(10)	107(9)	105(1.0)
Cycloate	83(9.6)	99(11)	120(4.2)	106(4.7)
EPTC	72(5.6)	99(10)	120(9.2)	109(1.8)
Molinate	82(6.1)	99(11)	124(5.7)	107(1.5)
Pebulate	75(1.3)	97(9.3)	124(3.0)	109(3.7)
Vernolate	77(3.9)	99(10)	124(1.6)	109(1.9)

(a) Average of duplicate extractions; percent relative range given in parenthesis.

CLEANUP

The six thiocarbamates eluted in silica gel fractions 2-4, which were obtained by elution with six, 15, and 50 percent ethyl ether in petroleum ether. Recoveries of the compounds were greater than 90 percent. Recovery data are given in Table 2. Elution order of the six compounds is given in Table 3.

TABLE 2. RECOVERIES OF THIOCARBAMATES FROM SIX PERCENT DEACTIVATED SILICA GEL

Compound	Recovery at Specified Spike Level, %	
	10 µg(a)	100 µg(b)
Butylate	102(20	111
Cycloate	121(12)	101
EPTC	99(13)	106
Molinate	98(16)	105
Pebulate	91(12)	102
Vernolate	92(14)	103

(a) Average of duplicate analyses; percent relative range given in parenthesis.
(b) Single analysis.

TABLE 3. ELUTION ORDER OF THIOCARBAMATES FROM SIX PERCENT DEACTIVATED SILICA GEL

Compound	Elution in Specified Fraction(a)		
	F2	F3	F4
Butylate	X	X	
Cycloate		X	
EPTC		X	
Molinate			X
Pebulate		X	
Vernolate		X	

(a) F2 = 6% ethyl ether in petroleum ether
F3 = 15% ethyl ether in petroleum ether
F4 = 50% ethyl ether in petroleum ether

CHROMATOGRAPHY

Both an 3% SP-2250 column and an 3% SP-1000 column were satisfactory for the determination of the six thiocarbamates. The 3% SP-2250 column, however, gave better peak shape and was chosen as the primary column. The following conditions were used for the primary column:

Column:	2 m x 2 mm I.D. glass column packed with 3% SP-2250 on 100/120 mesh Supelcoport
Detector:	AFD, 16 bead volts
Injector Temperature:	250° C
Detector Temperature:	300° C
Oven Temperature:	80° C isothermal for 4 min; programmed from 80° C to 300° C at 8° C/min; 300° C isothermal for 4 min.
Carrier Gas:	Helium at 30 mL/min.

A chromatogram obtained under these conditions is shown in Figure 1.

The following conditions were uscd for the alternate column:

Column:	2 m x 2 mm I.D. glass column packed with 3% SP-2100 on 100/120 mesh Supelcoport
Detector:	AFD, 16 bead volts
Injector Temperature:	250°C
Detector Temperature:	250°C
Oven Temperature:	80°C isothermal for 10 min; programmed from 80°C to 250°C at 8°C/min; 250°C isothermal for 10 min.
Carrier Gas:	Helium at 30 mL/min.

A chromatogram obtained under these conditions is shown in Figure 2.

VALIDATION STUDIES

The MDLs for the thiocarbamates generally ranged from 0.6 to 1.6 µg/L. Recoveries and MDL data are given in Table 4. Recoveries of the thiocarbamates obtained during the analytical curve studies were greater than 85 percent except for cycloate at the 10 µg/mL concentration level (81 percent). The resultant analytical curves were linear in the concentration range of 10 to 1000 µg/L. Recovery data are given in Table 5. The analytical curves generated from the recovery data are shown in Figures 3-8.

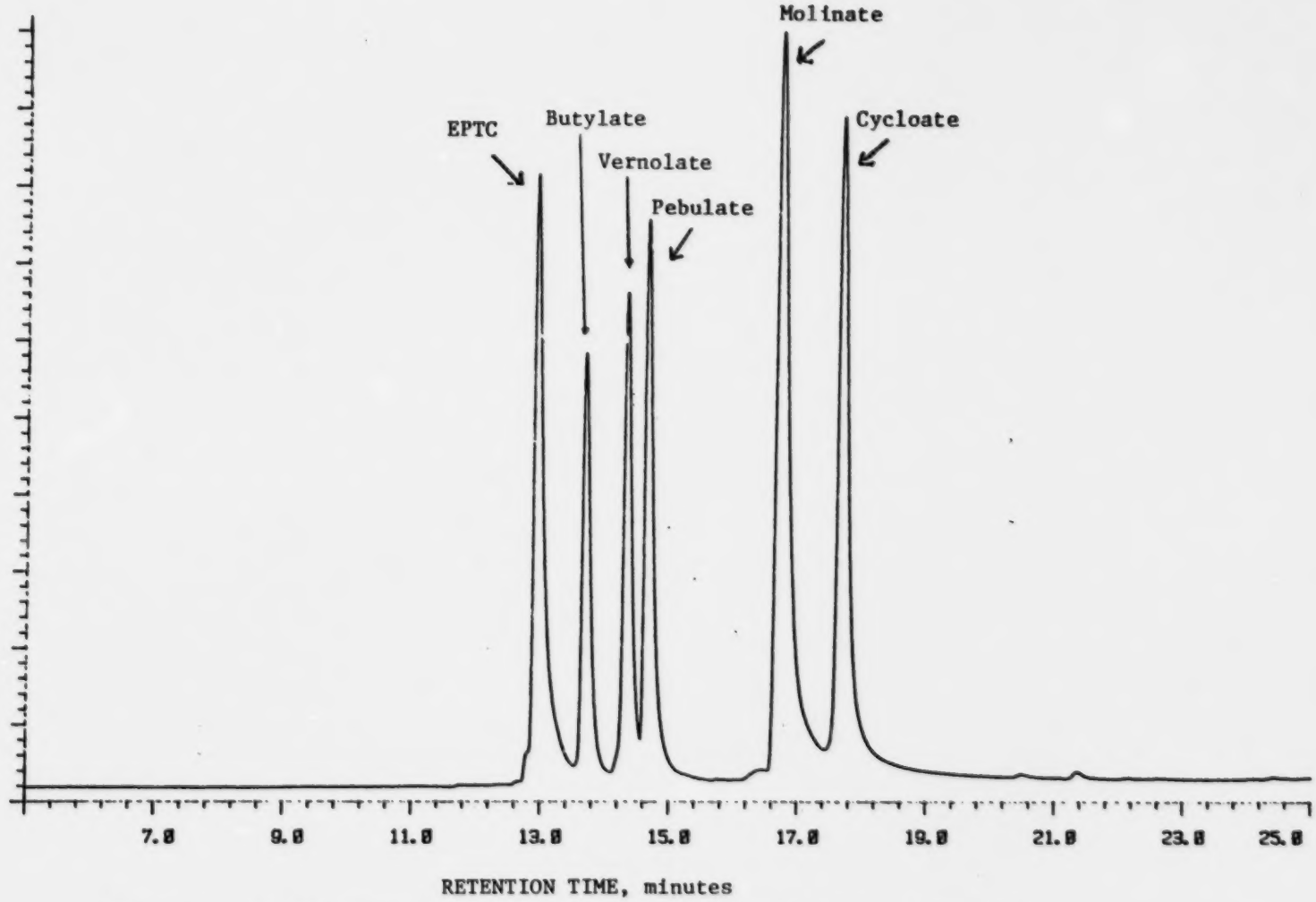


Figure 1. GC-AFD Chromatogram of 200ng of Each Thiocarbamate (Column 1).

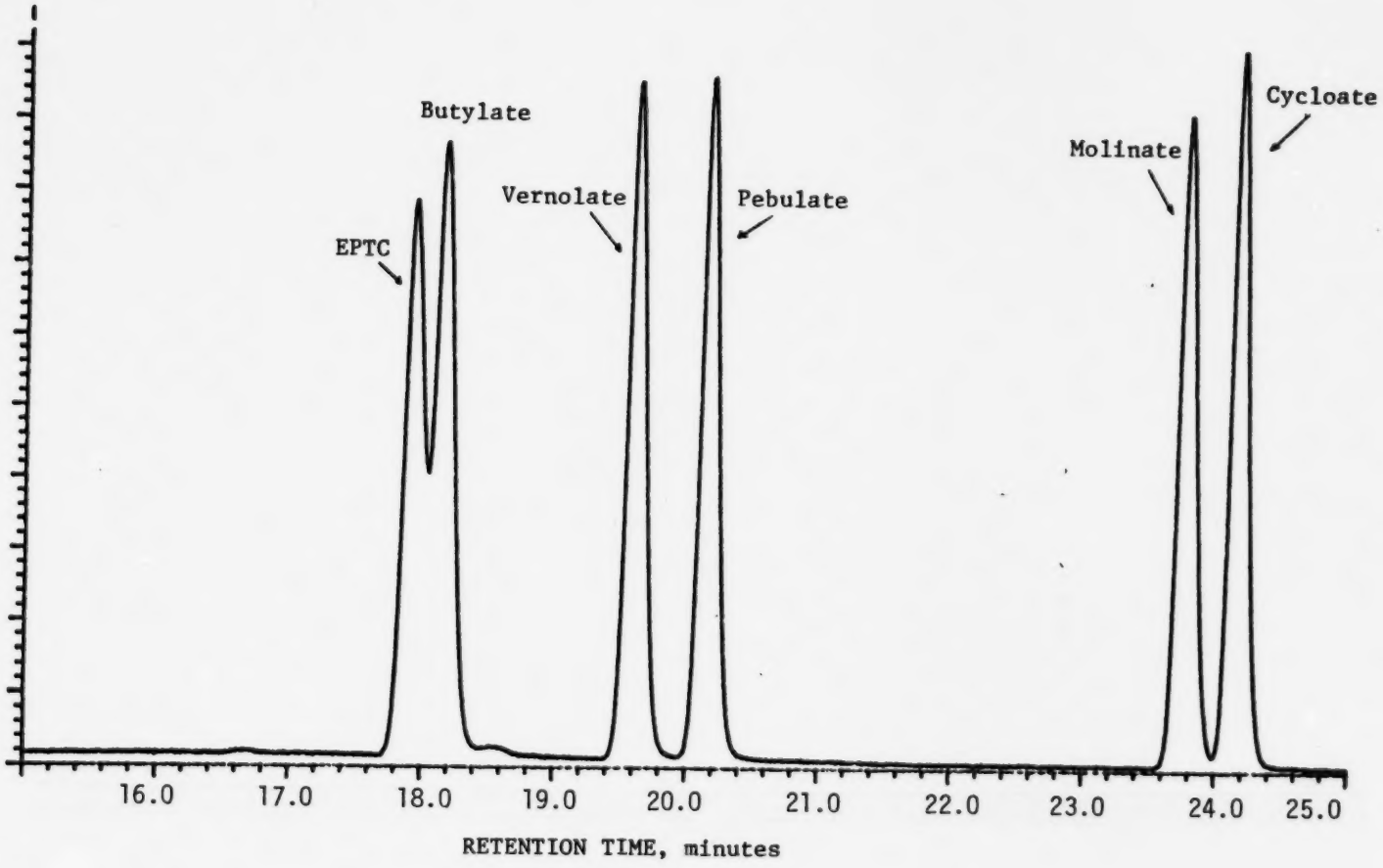


Figure 2. GC-AFD Chromatogram of 200ng of Each Thiocarbamate (Column 2).

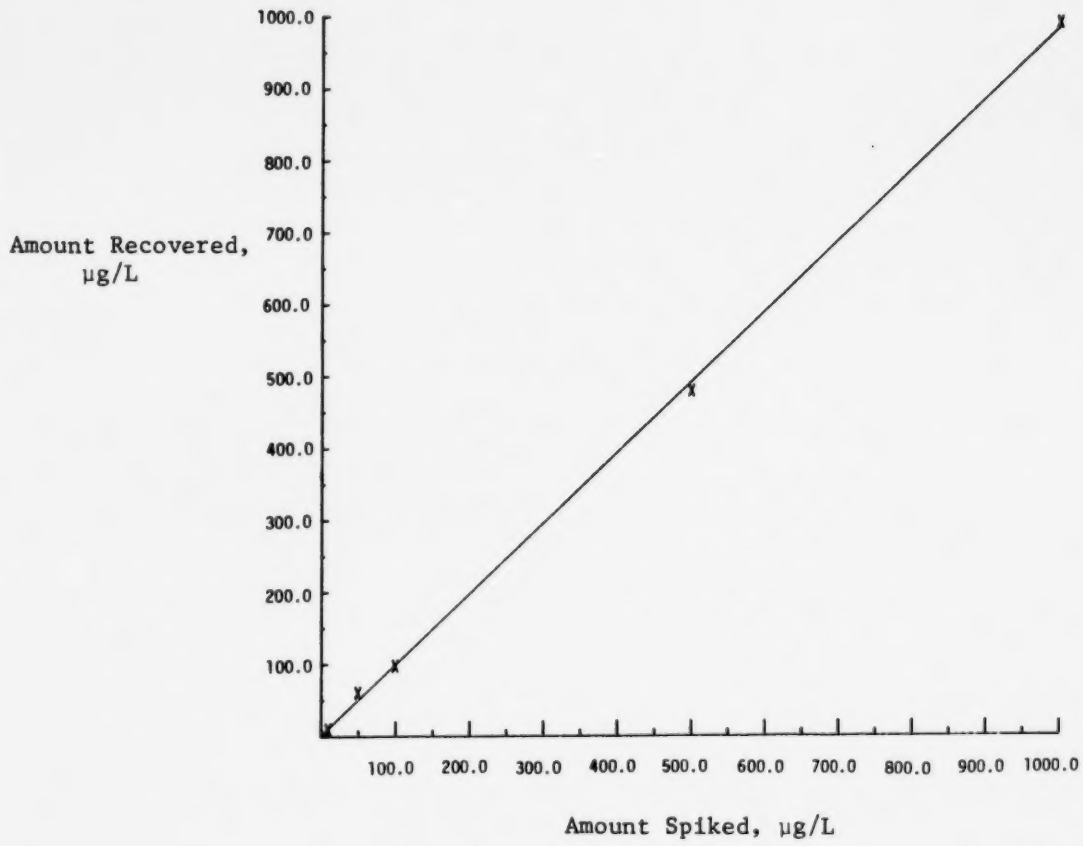


Figure 3. Analytical Curve for Butylate

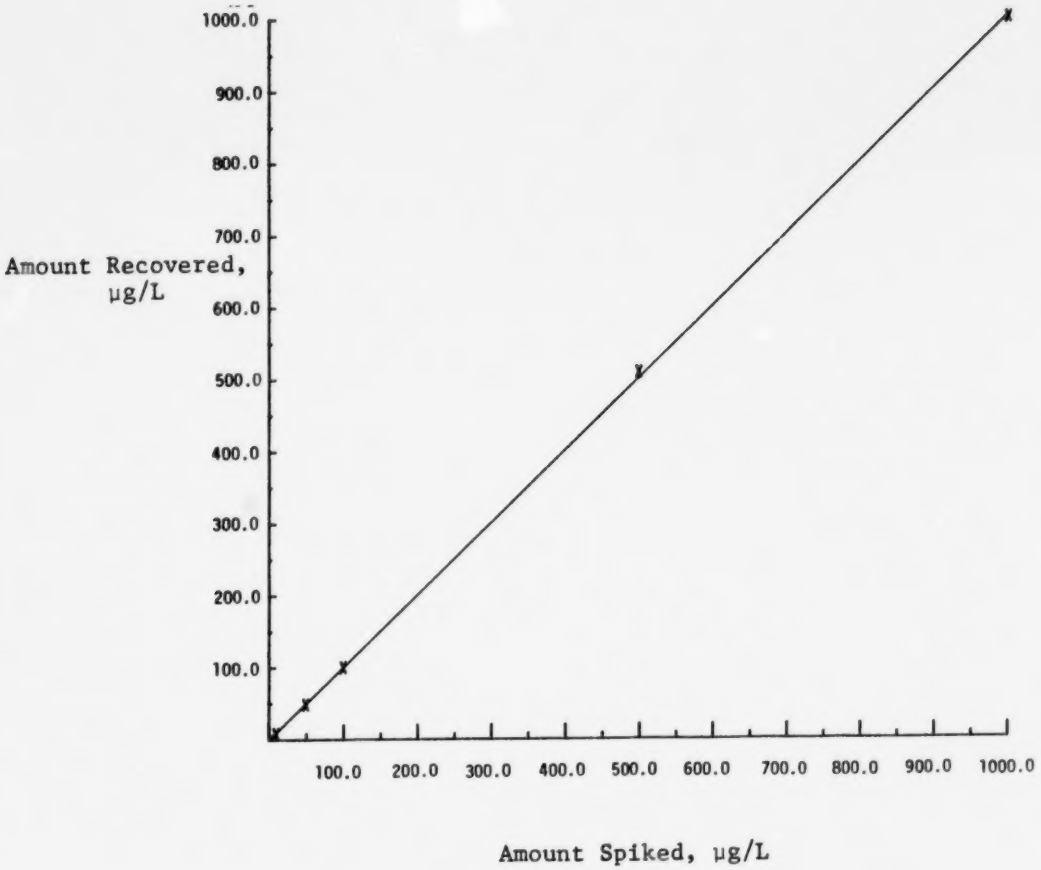


Figure 4. Analytical Curve for Cycloate.

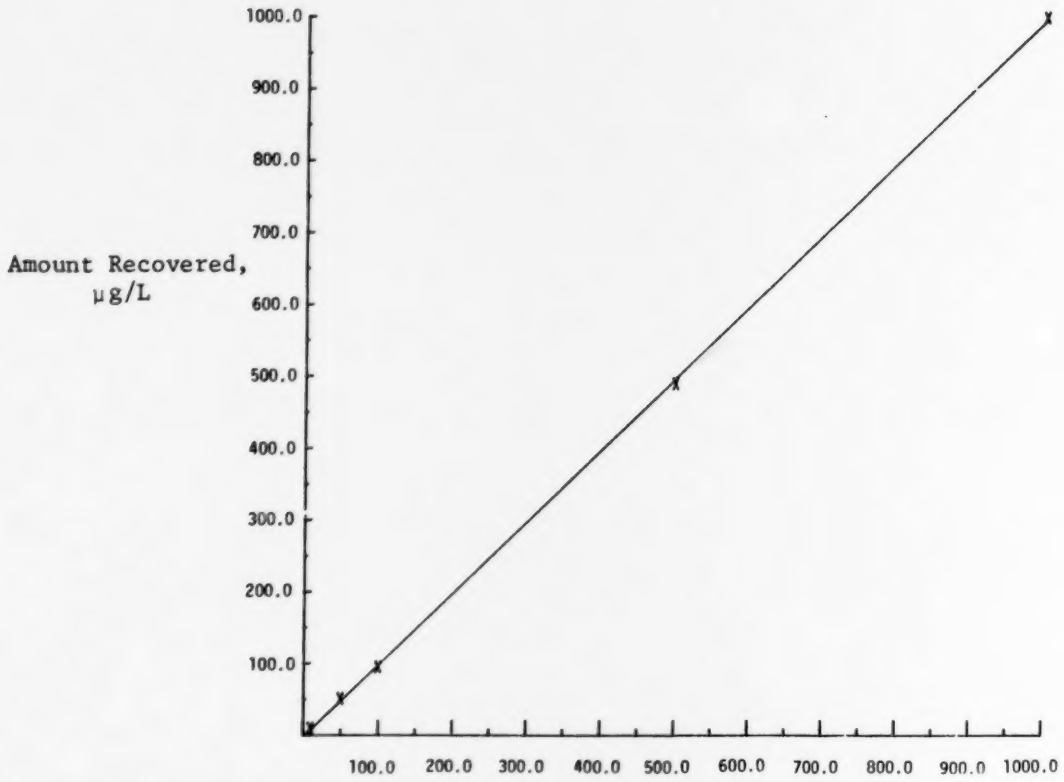


Figure 5. Analytical Curve for EPTC.

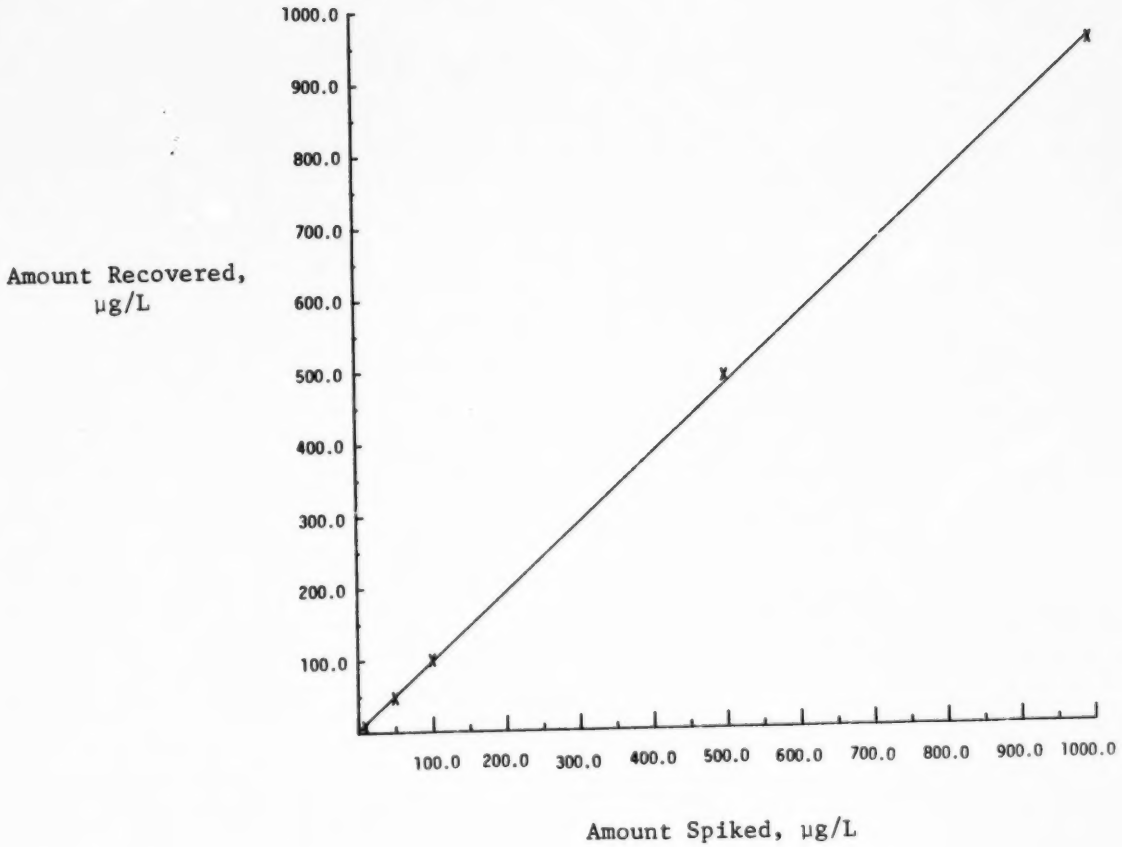


Figure 6. Analytical Curve for Molinate.

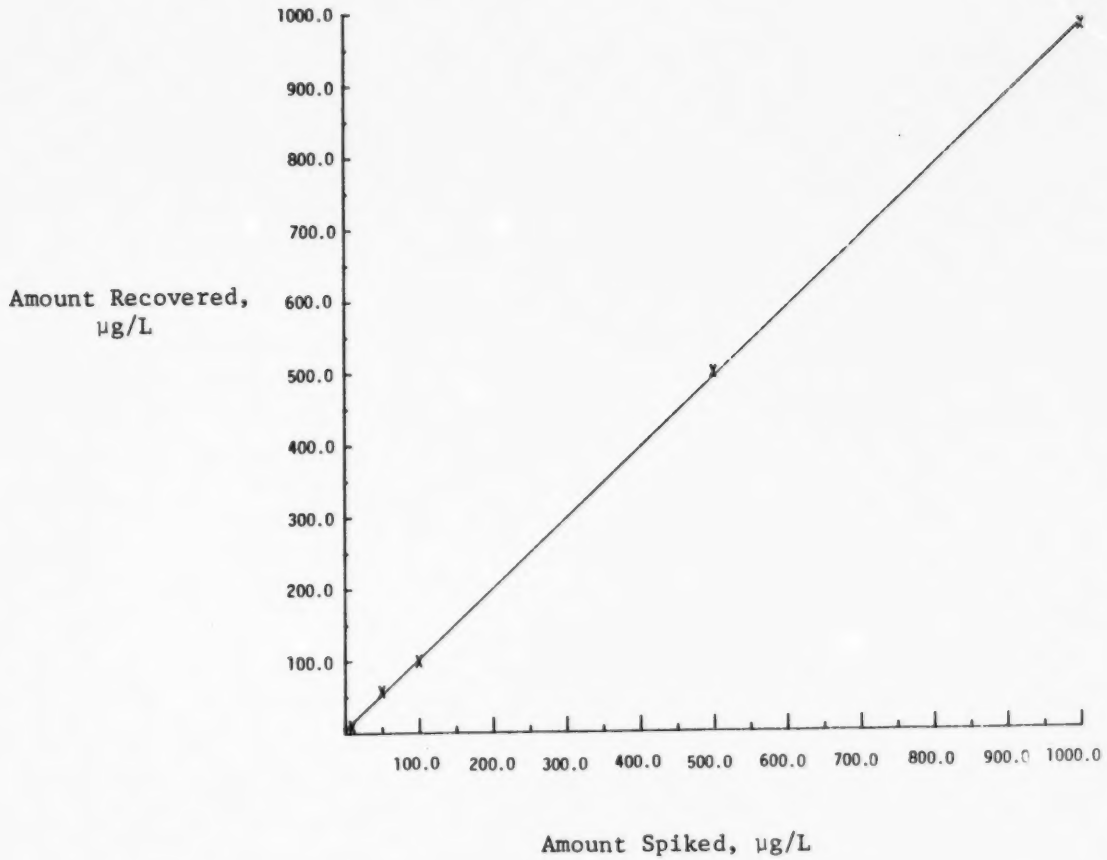


Figure 7. Analytical Curve for Pebulate

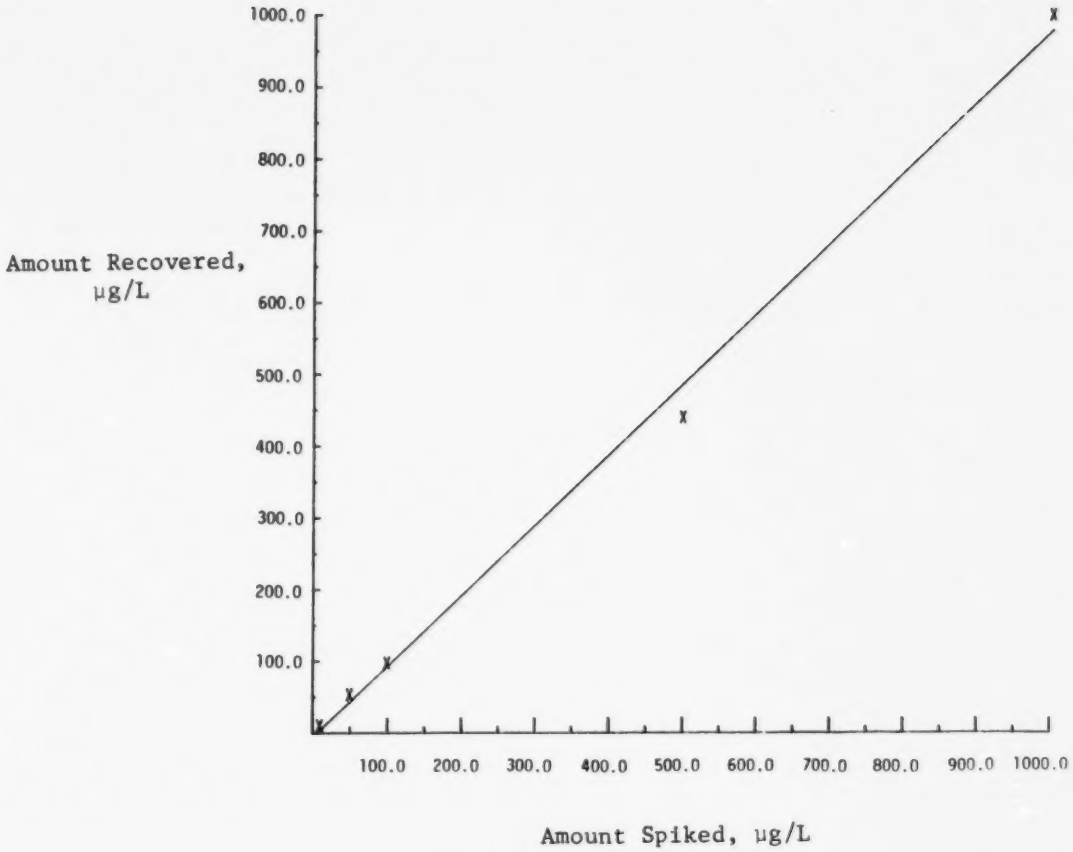


Figure 8. Analytical Curve for Vernolate.

TABLE 4. DATA FROM MDL DETERMINATION FOR THE THIOCARBAMATES

Compound	Amount Spiked, µg/L	Amount Recovered, µg/L(a)	MDL, µg/L
Butylate	5.0	4.8 ± 0.2	0.6
Cycloate	5.0	3.8 ± 0.5	1.6
EPTC	5.0	5.2 ± 0.3	0.9
Molinate	5.0	3.9 ± 0.2	0.6
Pebulate	5.0	4.8 ± 0.3	0.8
Vernolate	5.0	4.9 ± 0.3	1.1

(a) Average of seven replicate analyses.

TABLE 5. DATA FROM ANALYTICAL CURVE DETERMINATION FOR THE THIOCARBAMATES

	Amount Recovered at Given Spike Level, µg/L(a)				
Compound	10	50	100	500	1000
Butylate	9.9(8.5)	61(2.1)	98(3.7)	480(3.8)	990(0.3)
Cycloate	8.1(2.2)	49(9.4)	100(8.7)	510(3.3)	1000(2.9)
EPTC	10(3.8)	51(3.5)	95(8.0)	490(4.3)	1000(1.0)
Molinate	8.5(12)	48(5.0)	100(8.2)	490(4.9)	950(1.3)
Pebulate	9.9(3.0)	58(3.5)	100(9.0)	500(3.8)	980(14)
Vernolate	11(19)	54(15)	98(9.9)	440(3.9)	1000(3.3)

(a) Average of duplicate analyses; percent relative range given in parenthesis.

Recoveries of the thiocarbamates from wastewater at the 5 and 50 µg/L levels were in the range of 80 to 100 percent. Recovery data from the analyses of thiocarbamates in Columbus POTW secondary effluent are given in Table 6. Chromatograms of Columbus POTW secondary effluent, unspiked and spiked at the 50 µg/L level are shown in Figure 9. No interferences were observed in the unspiked wastewater.

TABLE 6. RECOVERIES OF THIOCARBAMATES FROM WASTEWATER

Compound	Wastewater(a)	Spike Level µg/L	Average Recovery, %(b)	Relative Standard Deviation, %
Butylate	1	5	80	18
	1	50	95	7
Cycloate	1	5	93	16
	1	50	95	7
EPTC	1	5	100	18
	1	50	100	5
Molinate	1	5	87	17
	1	50	93	8
Pebulate	1	5	97	26
	1	50	98	6
Vernolate	1	5	93	18
	1	50	96	10

(a) 1 = Columbus POTW secondary effluent.
(b) Average of seven replicate analyses.

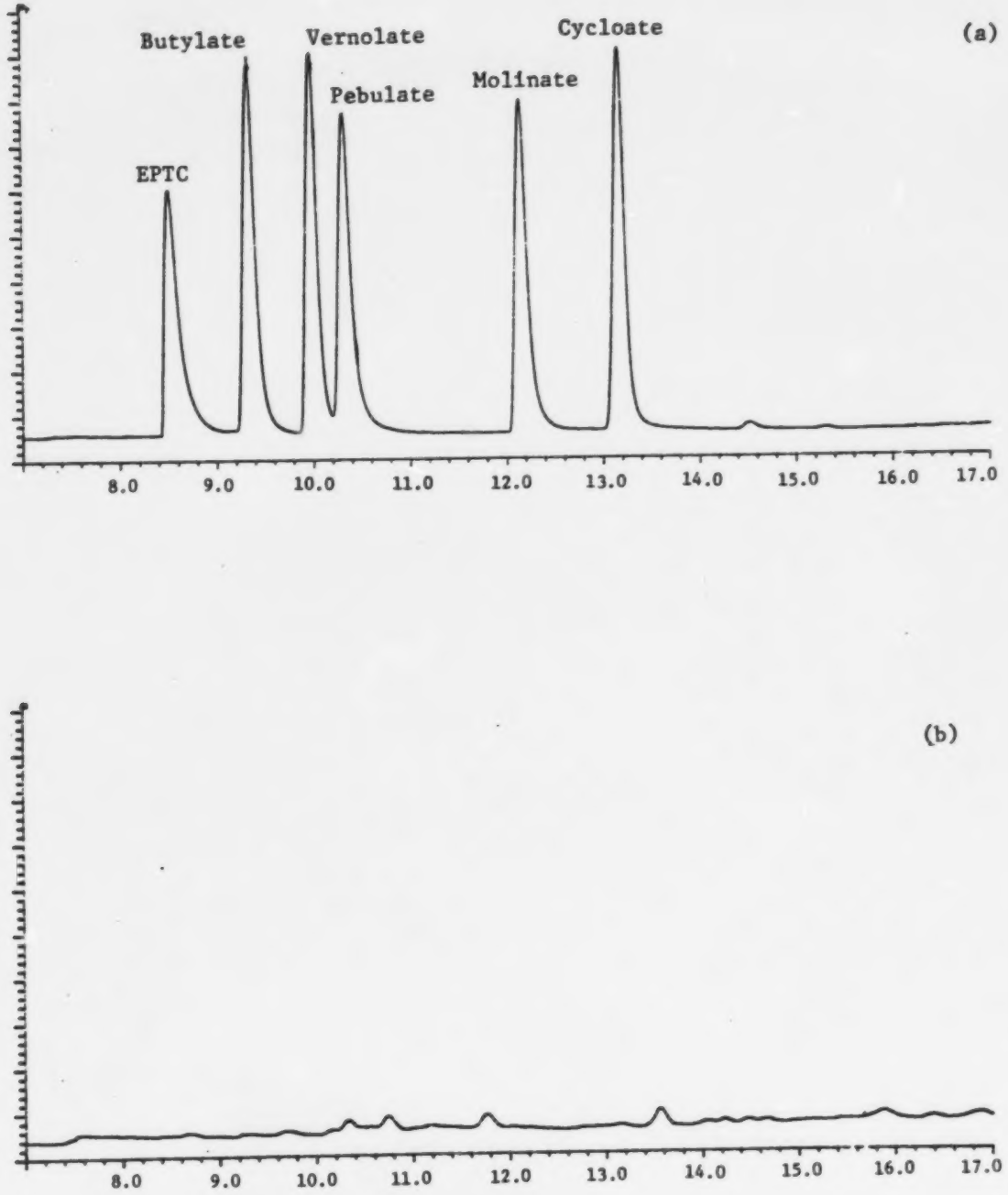


Figure 9. GC-FID Chromatograms of Extract from Columbus Secondary POTW Effluent (a) Spiked at the 50 µg/L Level With the Thiocarbmates and (b) Unspiked.

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DETERMINATION OF THIOCARBAMATE PESTICIDES IN INDUSTRIAL AND MUNICIPAL WASTEWATERS BY GAS CHROMATOGRAPHY

METHOD 634

1. Scope and Application

1.1 This method covers the determination of certain thiocarbamate pesticides. The following parameters can be determined by this method:

Parameter	CAS No.
Butylate	2008-41-5
Cycloate	1134-23-2
EPTC	759-94-4
Molinate	2212-67-1
Pebulate	1114-71-2
Vernolate	1929-77-7

1.2 This is a gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. Any modification of this method beyond those expressly permitted shall be considered a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.3 The method detection limit (MDL, defined in Section 15) for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 The sample extraction and concentration steps in this method are similar to other 600 series methods. Thus, a single sample may be extracted to measure the compounds included in the scope of the methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, in order to apply appropriate cleanup procedures.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the use of gas chromatography and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

1.6 When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Section 14 provides gas chromatograph/mass spectrometer (GC-MS) criteria appropriate for the qualitative confirmation of compound identifications.

2. Summary of Method

2.1 A measured volume of sample, approximately 1 liter, is solvent extracted with methylene chloride using a continuous extractor. The methylene chloride extract is dried and concentrated to 5.0 ml. Gas chromatographic conditions are described which permit the separation and measurement of the compounds in the extract by alkali flame detector (AFD) gas chromatography.[1]

2.2 This method provides an optional silica gel column cleanup procedure to aid in the elimination of interferences which may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing apparatus that lead to discrete artifacts or elevated baselines in gas chromatograms. All reagents and apparatus must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.5.

3.1.1 Glassware must be scrupulously cleaned.[2] Clean all glassware as soon as possible after use by thoroughly rinsing with the last solvent used in it. Follow by washing with hot water and detergent and thorough rinsing with tap and reagent water. Drain dry, and heat in an oven or muffle furnace at 400°C for 15 to 30 min. Thermally stable materials such as PCBs, might not be eliminated by this treatment. Thorough rinsing with acetone and pesticide quality hexane may be substituted for the heating. After drying and cooling, seal and store glassware in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are coextracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedure in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[3-5] for the information of the analyst.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle - Amber borosilicate or flint glass, 1-liter or 1-quart volume, fitted with screw caps lined with Teflon. Aluminum foil may be substituted for Teflon

if the sample is not corrosive. If amber bottles are not available, protect samples from light. The container and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional) - Must incorporate glass sample containers for the collection of a minimum of 250 mL. Sample containers must be kept refrigerated at 4°C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with reagent water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All Specifications are suggested. Catalog numbers are included for illustration only.)

5.2.1 Continuous extractor, 2000 mL, Hirschberg-Wolf, (Paxton Woods Glass Shop #1029 or equivalent).

5.2.2 Drying column - Chromatographic column 400 mm long x 10 mm ID.

5.2.3 Chromatographic column - 400 mm long x 19 mm ID with 250-mL reservoir at the top and Teflon stopcock (Kontes K-420290 or equivalent).

5.2.4 Concentrator tube, Kuderna-Danish - 25 mL, graduated (Kontes K-570050-1025 or equivalent). Calibration must be

checked at the volumes employed in the test. A ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish - 500 mL (Kontes K-570001-0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna-Danish - three-ball macro (Kontes K-503000-0121 or equivalent).

5.2.7 Snyder column, Kuderna-Danish - two-ball micro (Kontes K-569001-0219 or equivalent).

5.2.8 Vials - Amber glass, 10- to 15-mL capacity with Teflon-lined screw cap.

5.2.9 Volumetric flask - 5 mL with glass stopper.

5.2.10 Volumetric flask - 10 mL with glass stopper.

5.2.11 Graduated cylinder - 1000 mL.

5.3 Boiling chips - approximately 10/40 mesh carborundum. Heat to 400°C for 4 hours or extract in a Soxhlet extractor with methylene chloride.

5.4 Water bath - Heated, capable of temperature control (±2°C). The bath should be used in a hood.

5.5 Balance - Analytical, capable of accurately weighing to the nearest 0.0001 g.

5.6 Gas chromatograph - Analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1 - 180-cm-long x 2-mm-ID glass, packed with 3% SP-2250 on Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statements in Section 15. Guidelines for the use of alternate columns are provided in Section 12.1.

5.6.2 Column 2 - 180-cm-long x 2-mm-ID glass, packed with 3% SP-1000 on Supelcoport (100/120 mesh) or equivalent.

5.6.3 Detector - Alkali-flame detector (AFD), sometimes referred to as a nitrogen-phosphorus detector (NPD) or a thermionic specific detector (TSD). This detector has proven effective in the analysis of wastewaters for the compounds listed in the scope and was used to develop the method performance statements in Section 15. Alternative detectors, including a mass spectrometer, may be used in accordance with the provisions described in Section 12.1.

6. Reagents

6.1 Reagent water - Reagent water is defined as a water in which an interferent is not observed at the method detection limit of each parameter of interest.

6.2 Methylene chloride, methanol, petroleum ether, ethyl ether, toluene--distilled-in-glass quality or equivalent. Ethyl ether must be free of peroxides as indicated by EM Quant Test Strips (available from Scientific Products Co., Catalog No. P1126-8 and other suppliers). Procedures recommended for removal of peroxides are provided with the test strips.

6.3 Sodium sulfate (ACS)--Granular, anhydrous; heated in a muffle furnace at 400°C overnight.

6.4 Silica gel - Davision Grade 923, 100-200 mesh; activated by heating for 24 hours at 150°C.

6.5 6 N Sodium hydroxide. Dissolve 24.0 grams NaOH in 100 mL distilled water.

6.6 6 N Sulfuric acid. Slowly add 16.6 mL conc. H_2SO_4 to 50 mL distilled water and dilute to 100 mL with distilled water.

6.7 Stock standard solutions (1.00 µg/µL) - Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.7.1 Prepare stock standard solutions by accurately weighing about 0.0100 gram of pure material. Dissolve the material in distilled-in-glass quality methanol and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. If compound purity is certified at 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.7.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4°C and protect from light. Frequently check stock standard solutions for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7.3 Stock standard solutions must be replaced after 6 months or sooner if comparison with check standards indicates a problem.

7. Calibration

7.1 Establish gas chromatographic operating parameters equivalent to those indicated in Table 1. The gas chromatographic system may be calibrated using either the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 For each compound of interest, prepare calibration standards at a minimum of three concentration levels by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with toluene. One of the external standards should be at a concentration near, but above, the method detection limit. The other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL of each calibration standard, tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each parameter. Alternatively, the ratio of the response to the mass injected, defined as the calibration factor (CF), can be calculated for each compound at each standard concentration. If the relative standard deviation of the calibration factor is less than 10% over the working range, the average calibration factor can be used in place of a calibration curve.

7.2.3 The working calibration curve or calibration factor must be verified on each working shift by the measurement of one or more calibration standards. If the response for any compound varies from the predicted response by more than ±10%, the test must be repeated using a fresh calibration standard. Alternatively, a new calibration curve or calibration factor must be prepared for that parameter.

7.3 Internal standard calibration procedure. To use this approach, the analyst must select one or more internal standards similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Due to these limitations, no internal standard applicable to all samples can be suggested, although carbazole has been used successfully in some instances.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with toluene. One of the standards should be at a concentration near, but above, the method detection limit. The other concentrations should correspond to the expected range of concentrations found in real samples, or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL of each calibration standard, tabulate the peak height or area responses against the concentration for each compound and internal standard. Calculate response factors (RF) for each compound as follows:

$$RF = (A_s C_{is})/(A_{is} C_s)$$

where:

A_s = Response for the compound to be measured

A_{is} = Response for the internal standard

C_{is} = Concentration of the internal standard in µg/L

C_s = Concentration of the compound to be measured in µg/L.

If the RF value over the working range is constant, less than 10% relative standard deviation, the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is} against RF.

7.3.3 The working calibration curve or RF must be verified on each working shift by the measurement of one or more calibration standards. If the response for any compound varies from the predicted response by more than $\pm$10%, the test must be repeated using a fresh calibration standard. Alternatively, a new calibration curve must be prepared for that compound.

7.4 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory using this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and the analysis of spiked samples as a continuing check on performance. The laboratory is required to maintain performance records to define the quality of data that are generated.

8.1.1 Before performing any analyses, the analyst must demonstrate the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of the rapid advances occurring in chromatography, the analyst is permitted certain options to improve the separations or lower the cost of measurements. Each time such modifications to the method are made, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 The laboratory must spike and analyze a minimum of 10% of all samples to monitor continuing laboratory performance. This procedure is described in Section 8.4.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 Select a representative spike concentration for each compound to be measured. Using stock standards, prepare a quality control check sample concentrate in methanol 1000 times more concentrated than the selected concentrations.

8.2.2 Using a pipet, add 1.00 mL of the check sample concentrate to each of a minimum of four 1000-mL aliquots of reagent water. A representative wastewater may be used in place of the reagent water, but one or more additional aliquots must be analyzed to determine background levels, and the spike level must exceed twice the background level for the test to be valid. Analyze the aliquots according to the method beginning in Section 10.

8.2.3 Calculate the average percent recovery (R), and the standard deviation of the percent recovery (s), for the results. Wastewater background corrections must be made before R and s calculations are performed.

8.2.4 Using the appropriate data from Table 2, determine the recovery and single operator precision expected for the method, and compare these results to the values measured in Section 8.2.3. If the data are not comparable, the analyst must review potential problem areas and repeat the test.

8.3 The analyst must calculate method performance criteria and define the performance of the laboratory for each spike concentration and parameter being measured.

8.3.1 Calculate upper and lower control limits for method performance as follows:

Upper Control Limit (UCL) = R + 3 s

Lower Control Limit (LCL) = R - 3 s

where R and s are calculated as in Section 8.2.3. The UCL and LCL can be used to construct control charts[6] that are useful in observing trends in performance.

8.3.2 The laboratory must develop and maintain separate accuracy statements of laboratory performance for wastewater samples. An accuracy statement for the method is defined as $R \pm s$. The accuracy statement should be developed by the analysis of four aliquots of wastewater as described in Section 8.2.2, followed by the calculation R and s. Alternately, the analyst may use four wastewater data points gathered through the requirement for continuing quality control in Section 8.4. The accuracy statements should be updated regularly.[6]

8.4 The laboratory is required to collect in duplicate a portion of their samples to monitor spike recoveries. The frequency of spiked sample analysis must be at least 10% of all samples or one sample per month, whichever is greater. One aliquot of the sample must be spiked and analyzed as described in Section 8.2. If the recovery for a particular compound does not fall within the control limits for method performance, the results reported for that compound in all samples processed as part of the same set must be qualified as described in Section 13.3. The laboratory should monitor the frequency of data so qualified to ensure that it remains at or below 5%.

8.5 Before processing any samples, the analyst should demonstrate though the analysis of a 1-liter aliquot of reagent water that all glassware and reagents interferences are under control. Each time a set of samples is extracted or there is a change in reagents, a laboratory reagent blank should be processed as a safequard against laboratory contamination.

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to monitor the precision of the sampling techniuqe. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should perform analysis of standard reference materials and participate in relevant performance evaluation studies.

9. Samples Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[7] should be followed; however, the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of plastic and other potential sources of contamination.

9.2 The samples must be iced or refrigerated at 4°C from the time of collection until extraction.

9.3 Adjust the pH of the sample to 6 to 8 with 6 N sodium hydroxide or 6 N sulfuric acid immediately after sampling.

10. Sample Extraction

10.1 Assemble continuous extraction apparatus by placing 5-10 carborundum chips into the 500-mL round-bottom flask and attaching to the extraction flask.

10.2 Add 400 mL methylene chloride to the extraction flask. Some methylene chloride should displace into the round-bottom flask.

10.3 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into the extraction flask and add sufficient distilled water to fill extraction flask (two liters total volume aqueous phase).

10.4 Check the pH of the sample with wide range pH paper and adjust to 6 to 8 with 6 N sodium hydroxide or 6 N sulfuric acid.

10.5 Connect the stirring apparatus to the extraction flask without the frit touching the sample. Heat the methylene chloride in the round-bottom flask to continuous reflux and continue heating for 30 minutes to 1 hour until frit is thoroughly wetted with methylene chloride.

10.6 Lower frit until it just touches the sample and start the stirring apparatus rotating.

10.7 Continuously extract sample for 18-24 hours.

10.8 Assemble a Kuderna-Danish (K-D) concentrator by attaching a 25-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K-D if the requirements of Section 8.2 are met.

10.9 Pour the extract from the round-bottom flask through a drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K-D concentrator. Rinse the flask and

column with 20 to 30 mL of methylene chloride to complete the quantitative transfer. Once the flask rinse has passed through the drying column, rinse the column with 30 to 40 mL of methylene chloride.

10.10 Add 1 or 2 clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL methylene chloride to the top. Place the K-D apparatus on a hot water bath, 60 to 65°C, so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K-D apparatus and allow it to drain and cool for at least 10 min.

10.11 Remove the Snyder column and flask and adjust the volume of the extract to 5.0 mL with methylene chloride. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract is to be stored longer than 2 days, transfer the extract to a screw-capped vial with a Teflon-lined cap. If the sample extract requires no further cleanup, proceed with solvent exchange to toluene as described in section 10.12, and then to gas chromatographic analysis as described in Section 12. If the sample requires cleanup, proceed to Section 11.

10.12 Add 2.5 mL of toluene and 1 or 2 clean boiling chips to the

extract in the 25-mL concentrator tube and attach a two-ball micro-Snyder column. Place the K-D apparatus in a hot water bath, 70 to 75°C. When the apparent volume of liquid reaches 2 to 2.5 mL, remove the K-D apparatus and allow it to drain and cool for at least 10 min. Transfer the sample to a 5-mL volumetric flask and dilute to 5-mL with toluene. Proceed with gas chromatographic analysis.

10.13 Determine the original sample volume by refilling the sample bottle to the mark and transferring the water to a 100-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relative clean sample matrix. The cleanup procedure recommended in this method has been used for the analysis of various clean waters and industrial effluents. If particular circumstances demand the use of an alternative cleanup procedure, the analyst must determine the elution profile and demonstrate that the recovery of each compound of interest is no less than 85%.

11.2 Add 20 g of silica gel to a mixture of 100 mL of acetone and 1.2 mL of reagent water and stir for 30 minutes on a stirring plate. Transfer the slurry to a chromatographic column (silica gel may be retained with a plug of glass wool). Wash the column with 20 mL of methylene chloride followed by 30 mL petroleum ether. Allow the solvent to elute from the column until the silica gel is almost exposed to the air. Discard washings. Use a column flow rate of 2 to 2.5 mL/min throughout the wash and elution profiles. Add an additional 50 mL of petroleum ether to the head of the column.

11.3 Add the extract from Section 10.12 to the petroleum ether suspended above column. Allow the solvent to elute from the column until the silica gel almost exposed to the air. Elute the column with 25 mL of petroleum ether (F1). Discard this fraction.

11.4 Elute the column with 100 mL of 50% ethyl ether in petroleum ether and collect in a K-D apparatus. Alternatively, separate fractions may be collected or combined at the discretion of the analyst. The elution profile of these compounds from silica gel is given in Table 3.

11.5 Concentrate the fraction to <5 mL after addition of 2.5 mL toluene as described in Section 10.12. Transfer sample to a 5-mL volumetric flask and dilute to 5 mL with toluene. Proceed with gas chromatographic analysis.

12. Gas Chromatography

12.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are estimated retention times and method detection limits that can be achieved by this method. An example of the separations achieved by Column 1 and Column 2 are shown in Figures 1 and 2. Other packed columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met. Capillary (open-tubular) columns may also be used if the relative standard deviations of responses for replicate injections are demonstrated to be less than 6% and the requirements of Section 8.2 are met.

12.2 Calibrate the gas chromatographic system daily as described in Section 7.

12.3 If an internal standard approach is being used, the analyst must not add the internal standard to sample extracts until immediately before injection into the instrument. Mix thoroughly.

12.4 Inject 2 to 5 µL of the sample extract using the solvent flush technique.[8] Record the volume injected to the nearest 0.05-µL, and the resulting peak sizes in area or peak height units.

12.5 The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.6 If the response for the peak exceeds the working range of the system, dilute the extract and reanalyze.

12.7 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor in Section 7.2.2. The concentration in the sample can be calculated as follows:

$$\text{Concentration, } \mu g/L = \frac{(A)(V_t)}{(V_i)(V_s)}$$

where:

A = Amount of material injected, in nanograms

V_i = Volume of extract injected in µL

V_t = Volume of total extract in µL

V_s = Volume of water extracted in mL.

13.1.2 If the internal standard calibration procedure was used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 as follows:

$$\text{Concentration, } \mu g/L = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

where:

A_s = Response for the compound to be measured

A_{is} = Response for the internal standard

I_s = Amount of internal standard added to each extract in µg

V_o = Volume of water extracted, in liters.

13.2 Report results in micrograms per liter without correction for recovery data. When duplicate and spiked samples are analyzed, report all data obtained with the sample results.

13.3 For samples processed as part of a set where the laboratory spiked sample recovery falls outside of the control limits in Section 8.3, data for the affected compounds must be labeled as suspect.

14. GC-MS Confirmation

14.1 It is recommended that GC-MS techniques be judiciously employed to support qualitative identifications made with this method. The

mass spectrometer should be capable of scanning the mass range from 35 amu to a mass 50 amu above the molecular weight of the compound. The instrument must be capable of scanning the mass range at a rate to produce at least 5 scans per peak but not to exceed 7 seconds per scan utilizing a 70-V (nominal) electron energy in the electron impact ionization mode. A GC to MS interface constructed of all-glass or glass-lined materials is recommended. When using a fused silica capillary column, the column outlet should be threaded through the interface to within a few millimeters of the entrance to the source ionization chamber. A computer system should be interfaced to the mass spectrometer that allows the continuous acquisition and storage on machine-readable media of all mass spectra obtained throughout the duration of the chromatographic program.

14.2 Gas chromatographic columns and conditions should be selected for optimum separation and performance. The conditions selected must be compatible with standard GC-MS operating practices. Chromatographic tailing factors of less than 5.0 must be achieved. The calculation of tailing factors is illustrated in Method 625.

14.3 At the beginning of each day that confirmatory analyses are to be performed, the GC-MS system must be checked to see that all DFTPP performance criteria are achieved.9

14.4 To confirm an identification of a compound, the background corrected mass spectrum of the compound must be obtained from the sample extract and compared with a mass spectrum from a stock or calibration standard analyzed under the same chromatographic conditions. It is recommended that at least 50 nanograms of material

be injected into the GC-MS. The criteria below must be met for qualitative confirmation.

14.4.1 The molecular ion and all other ions that are present above 10% relative abundance in the mass spectrum of the standard must be present in the mass spectrum of the sample with agreement to plus or minus 10%. For example, if the relative abundance of an ion is 30% in the mass spectrum of the standard, the allowable limits for the relative abundance of that ion in the mass spectrum for the sample would be 20-40%.

14.4.2 The retention time of the compound in the sample must be within 30 seconds of the same compound in the standard solution.

14.4.3 Compounds that have very similar mass spectra can be explicitly identified by GC-MS only on the basis of retention-time data.

14.5 Where available, chemical ionization mass spectra may be employed to aid in the qualitative identification process.

14.6 Should these MS procedures fail to provide satisfactory results, additional steps may be taken before reanalysis. These may include the use of alternate packed or capillary GC columns or additional cleanup (Section 11).

15. Method Performance

15.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero. The MDL concentrations listed in Table 1 were obtained using reagent water.[1]

15.2 This method has been tested for linearity of recovery from spiked reagent water and has been demonstrated to be applicable over the concentration range from 10 x MDL to 1000 x MDL.

15.3 In a single laboratory, Battelle's Columbus Laboratories, using spiked wastewater samples, the average recoveries presented in Table 2 were obtained. Seven replicates of each of two different wastewaters were spiked and analyzed. The standard deviation of the percent recovery is also included in Table 2.1

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TABLE 1. CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention Time (min) Column 1	Retention Time (min) Column 2	Method Detection Limit (µg/L)
EPTC	12.8	17.9	0.9
Butylate	13.5	18.2	0.6
Vernolate	14.2	19.6	1.1
Pebulate	14.5	20.2	0.8
Molinate	16.6	23.8	0.6
Cycloate	17.5	24.2	1.6

Column 1 conditions: Supelcoport (100/120 mesh) coated with 3% SP-2250 packed in a 1.8-m-long x 2-mm-ID glass column with helium carrier gas at a flow rate of 30 ml/min. Column temperature is held at 80°C for 4 minutes, programmed from 80°C to 300°C at 8°C/min and held at 300°C for 4 minutes.

Column 2 conditions: Supelcoport (100/120 mesh) coated with 3% SP-2100 packed in a 1.8-m-long x 2-mm-ID glass column with helium carrier gas at a flow rate of 30 ml/min. Column temperature is held at 80°C for 10 minutes, programmed from 80°C to 250°C at 8°C/min and held at 250°C for 10 minutes.

TABLE 2. SINGLE LABORATORY ACCURACY AND PRECISION(a)

Parameter	Average Percent Recovery	Relative Standard Deviation, %	Spike Level (µg/L)	Number of Analyses	Matrix Type(b)
Butylate	80	18	5.0	7	1
	95	7.2	50	7	1
Cycloate	93	16	5.0	7	1
	95	7.3	50	7	1
EPTC	100	18	5.0	7	1
	100	4.8	50	7	1
Molinate	87	17	5.0	7	1
	93	8.4	50	7	1
Pebulate	97	26	5.0	7	1
	98	5.7	50	7	1
Vernolate	93	18	5.0	7	1
	96	10	50	7	1

(a) Column 1 conditions were used.

(b) 1 = Secondary POTW effluent.

TABLE 3. ELUTION CHARACTERISTICS OF THE THIOCARBAMATES FROM 6% DEACTIVATED SILICA GEL

Parameter	Appearance in Specified Fraction(a)			
	F1	F2	F3	F4
Butylate		X	X	
Cycloate			X	
EPTC			X	
Molinate				X
Pebulate			X	
Vernolate			X	

Eluant composition by fraction:

(a) F1 = 25 mL petroleum ether
F2 = 50 mL 6% ethyl ether in petroleum ether
F3 = 50 mL 15% ethyl ether in petroleum ether
F4 = 50 mL 50% ethyl ether in petroleum ether.

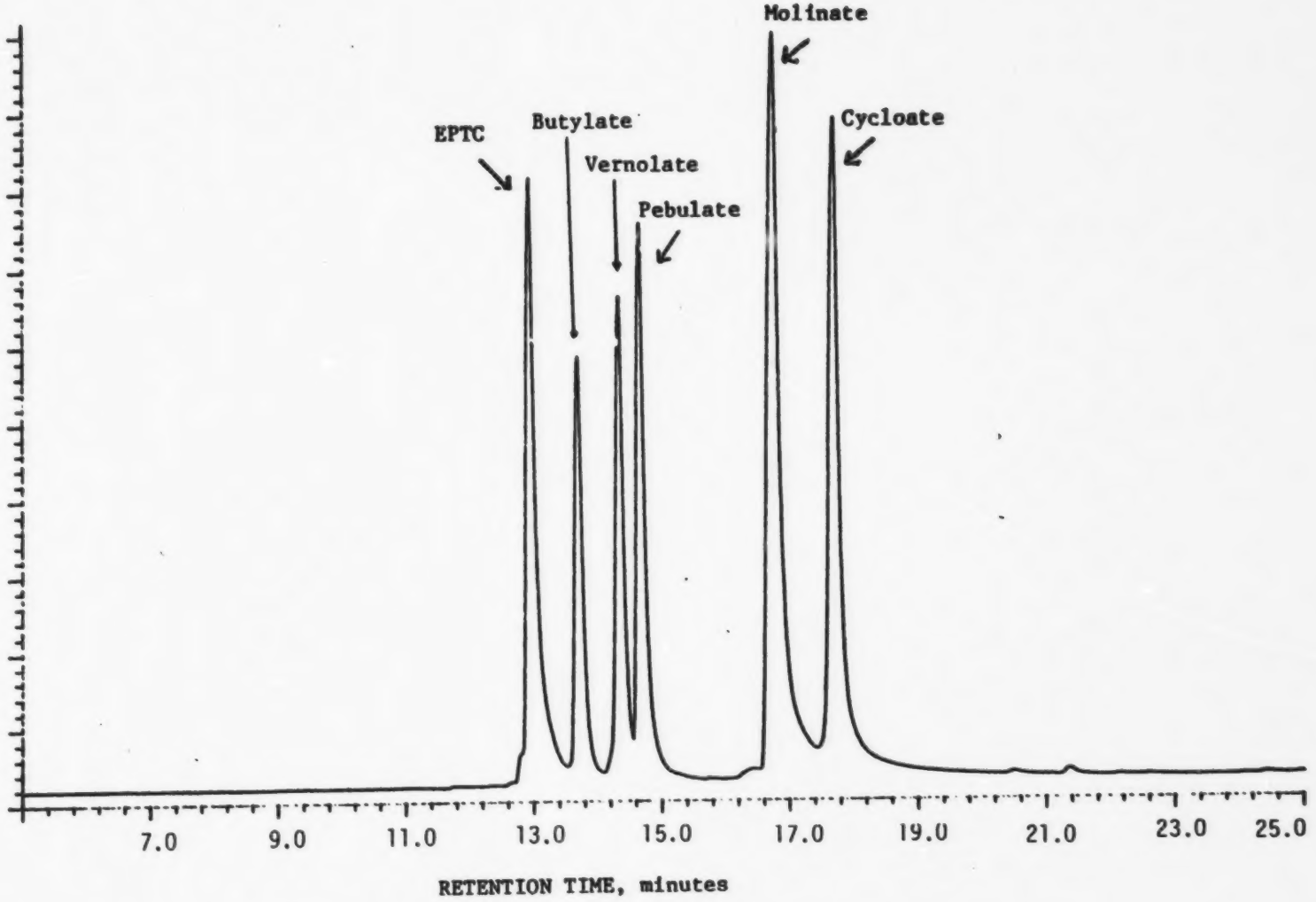

FIGURE 1. GC-AFD CHROMATOGRAM OF 200ng OF EACH THIOCARBAMATE (COLUMN 1).

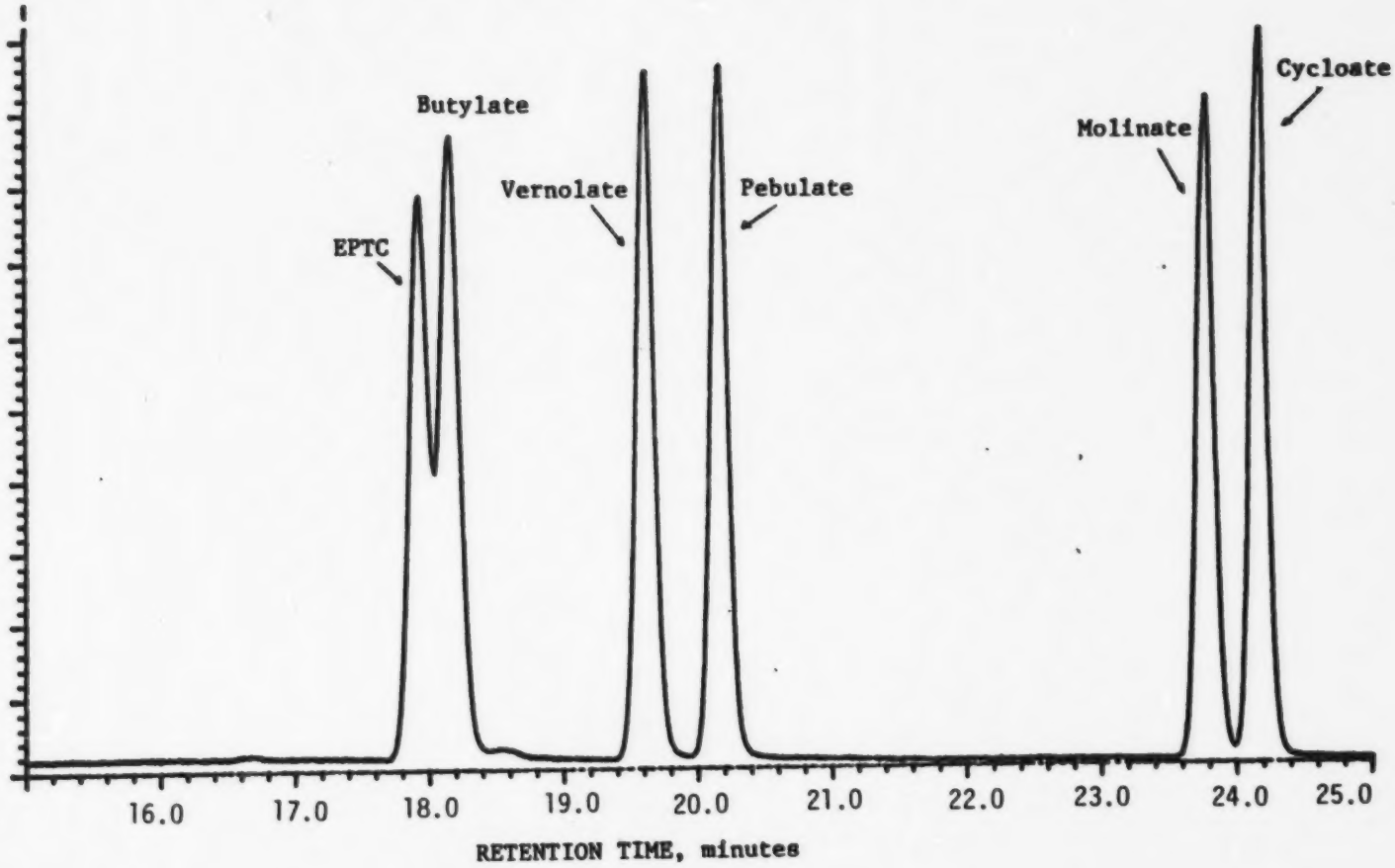

FIGURE 2. GC-AFD CHROMATOGRAM OF 200ng OF EACH THIOCARBAMATE (COLUMN 2).